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CALCULATION PACKAGE COVER SHEET

Client: Gowanus Canal Remedial Design Group (RD Group) **Project:** Gowanus Canal Superfund Site **Project #:** HPH106A

TITLE OF PACKAGE: **ECOLOGICAL HABITAT LAYER DESIGN**

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REVISION HISTORY:

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CP: **SS** Date: **5/19/2017** APC: **GDN** Date: **5/19/2017** CC: **MWS** Date: **5/19/2017**

Client: **RD Group** Project: **Gowanus Canal Superfund Site** Project No: **HPH106A**

ECOLOGICAL HABITAT LAYER DESIGN

INTRODUCTION AND PURPOSE

As outlined in the Record of Decision (ROD) (EPA, 2013), a multilayered capping system ("cap") will be constructed within the Canal to: (i) provide a layer at the bottom of the Canal that is physically stable and meets remedy performance criteria for contaminants of concern (COCs); and (ii) prevent unacceptable amounts of contaminants, including dissolved-phase constituents and residual non-aqueous phase liquids (NAPLs), from migrating at a level that can pose risk to ecological receptors from beneath the cap to surface layers and Canal surface water.

The cap, as illustrated in Figure 1 shall consist of the following three primary layers from the base layer to the surface: (i) an adsorptive treatment layer designed to sequester contaminants; (ii) a gravel isolation and filter layer; and (iii) an armor layer. The isolation and filter layer, along with gravel integrated into the armor layer, will also serve as an ecological habitat layer. Structural concrete for under water applications will be placed near bulkheads or in confined spaces. A sand based leveling layer is also planned for the base of the cap to provide a separation between the sediment and cap treatment layer and as a means of creating a more uniform surface elevation following dredging.

The ecological habitat layer is included as part of the armor layer based on the ROD requirement which states that "sufficient sand will be placed on top of the armor layer to fill in the voids between the stones and to establish sufficient depth of soft sediment in order to facilitate benthic recolonization" (EPA, 2013). Thus, the primary purpose of this calculation package is to evaluate the viability and utility of using a similar sized material like: (i) gravel placed into the armor layer; and (ii) gravel within the isolation and filter layer as an ecological habitat layer for remediation target area (RTA) 1 and 4th St. Turning Basin (TB4) Pilot Study Area, and if considered viable, selecting the appropriate grain size and thickness of the ecological habitat layer.

A figure presenting the extent of RTA1 and TB4 Pilot Study Area is provided as Figure 2.

METHODOLOGY AND ASSUMPTIONS

To understand the viability of the ecological habitat layer, a literature review of ecological habitat layer design for several capping projects and subaqueous cap design guidance was completed. Additionally, an evaluation of the hydrodynamic forces in RTA1 and TB4 was also completed to determine a suitable grain size for the ecological habitat layer. The following three subsections describe the literature review, material volume estimates, and hydrodynamic evaluations.

Literature Review of Ecological Habitat Layers

The thickness and grain size are two important design parameters for an ecological habitat layer. The thickness of the habitat layer is dependent on bioturbation depth, where bioturbation refers to the various processes used by benthic organisms to modify sediment properties or move sediment particles or solutes within the sediment matrix (Palermo et al. 1998). Surficial bioturbation (where the sediment is completely mixed) in coastal environments with sand caps is typically 10 centimeters (cm) [4 inches] (Clarke et al, 2001). The mid-depth zone of bioturbation in similar environments ranges from 10 to 35 cm (4 to 14 inches) yielding a total cap thickness of 20 to 45 cm (8 to 18 inches) to adequately address overall bioturbation. Additionally, the grain size of material used for the habitat layer plays an important role in determining the types of biota that will occupy the surficial sediments and ultimately the bioturbation effects on cap integrity and rate of benthic recolonization (Palermo et al. 1998; Clarke et al. 2001). Several sand capping projects were reviewed as part of the literature review and their thicknesses and material grain sizes (where described) are described in Table 1.

Volume of Ecological Habitat Layer Material

For the 100% TB4 Pilot Study and Preliminary (35%) RTA1 design, Articulated Concrete Block (ACB) mats are considered the most viable choice for armoring. To reduce the potential for erosion from hydrodynamic forces, gravel was chosen in lieu of sand within the voids of and between ACB mats. Both gravel and sand have been used for capping projects.

For RTA1, where a potential ACB layout has not been provided at the 35% design stage or locations where structural concrete will be placed, the total in-place volume of gravel placed within the voids of the ACBs mats was estimated by multiplying the area of RTA1 (approximately 4.79 acres) by the thickness of the ACB mats and % open area (20%). In the TB4 Pilot Study Area, in-place volumes were estimated by: (i) multiplying the area of the ACB mats by the thickness of the ACB mats and % open area; and (ii) adding the additional volume of gravel placed within the 2” gaps between individual ACB mats.

Similarly, the total in-place volume of the isolation and filter layer was calculated by multiplying the RTA1 and TB4 Pilot Study areas by the material thickness of six inches.

RTA1 volumes may be refined in later stages of the RTA1 design to account for construction losses, account for the proposed ACB mat layout, and locations where structural concrete for under water applications will be placed. The areas associated with the TB4 volumes are based on in-place volumes and account for the proposed ACB mat layout and where structural concrete will be placed.

Hydrodynamic Evaluations

For RTA1, the flow in the Canal is effected by hydrodynamic forces generated due to flushing tunnel operations, propeller wash impacts, combined sewer overflows (CSOs), and tidal effects (Baird, 2012; Baird, 2017; CH2M 2015).

Hydrodynamic characteristics (i.e., depth-averaged flow velocities, bed [or applied] shear stresses) for impacts due to flushing tunnel, storm surges, and tidal effects were analyzed by Baird (2012) based on existing bathymetric conditions. After dredging and capping, the flow velocities are expected to decrease due to the increased flow area. Multiple scenarios were analyzed by Baird including: (i) existing conditions during neap tide with moored barges; (ii) existing conditions during spring tide with moored barges; (iii) existing conditions during spring tide (without barges); (iv) flushing tunnel operating during spring tide with moored barges; (v) flushing tunnel operating during spring tide without moored barges; and (vi) during Hurricane Irene.

The highest peak bed shear stress and peak depth-averaged flow velocity were found to occur during flushing tunnel operations during spring tide with moored barges during ebb conditions. Baird (2012) completed this model assuming an average flushing tunnel flow of 215 million gallons per day (MGD) based on the Gowanus Canal Waterbody/Watershed Facility Plan Report (NYCDEP, 2008). Discharge from the flushing tunnel can range from 175 MGD to 252 MGD, with the highest discharge rates occurring during high tide conditions. In the scenario analyzed by Baird, the peak bed shear stress and peak depth-averaged flow velocity were estimated to be 1.44 Pascals (Pa) (equals 0.03 pounds per square foot [psf]) and 1.79 feet per second (fps) in the Canal, respectively. In TB4, which is sheltered, the depth-averaged flow velocities and bed shear stresses are significantly less than in the main channel of the Canal, (See Figures 3 and 4) and are estimated to range from 0 to 0.1 fps and 0 to 0.025 Pa (= 0 to 0.00052 psf), respectively (Baird, 2012). Data on flow and sediment inputs from CSOs were unavailable at the time of Baird (2012) study, and hence the hydrodynamic effects of CSO outfalls were not considered in the comparison although they are anticipated to be less than the flushing tunnel flows.

As presented in the armor layer calculation package provided as Appendix B10the largest bed velocities and bed shear stresses on the armoring layer would be due to propeller wash and no other hydrodynamic forces (e.g., flushing tunnel flows or storm surges). The calculated bed shear stresses caused by propeller wash impacts would require large riprap to resist erosion. Thus, an ecological habitat layer, if placed into the ACB mats would move near the surface when vessels are passing. Similarly, gravel placed into the voids of riprap would move near the surface due to periodic vessel traffic, if riprap was the selected design for armoring. After construction of the cap, however, it is anticipated that the vessels will only use RTA1 and TB4 Pilot Study Area periodically (e.g., for cap monitoring, maintenance dredging) and propeller wash impacts would be less frequent than hydrodynamic forces due to flushing tunnel operations, CSO discharges, and tidal effects. Thus, the appropriate grain size was selected based on having the material stable from other hydrodynamic forces (e.g., the material should not be eroded during flushing tunnel operations).

The grain size of material for the habitat layer (D_{50}) were estimated for both RTA1 and TB4 Pilot Study Area using the following three methods:

1) <u>Shields Critical Shear Stress (Shields, 1936)</u> – The FHWA (2012) report recommends a Critical Shields Stress (or Shields Parameter) of 0.03 for gravel (Meyer-Peter and Muller, 1948; Gessler, 1971). The Shields parameter was then substituted in the Shields equation (Shields, 1936) to calculate the D_{50} (m), where the peak bed shear stress in the Canal obtained from the Baird (2012) study was selected for evaluating the stability of gravel in RTA1 and the upper range of bed shear stresses observed in TB4 (See Figure 4) was used to evaluate gravel stability for the TB4 Pilot Study Area.

$$D_{50} = \frac{\tau_o}{(\theta c)\,(\rho_s - \rho) g} \qquad (1)$$

where:

τ_o is the peak bed shear stress (1.44 Pa for RTA1; 0.025 Pa for TB4 Pilot Study Area)

ρ_s is the density of sediment particle (2400 kg/m^3)

ρ is the density of water (seawater assumed to be 1025 kg/m^3)

g is the acceleration due to gravity (9.81 m/s^2)

2) <u>Hjulstrom Curve (Hjulstrom, 1935)</u> - The peak depth-averaged flow velocity obtained from Baird (2012) study was used for RTA1 (= 1.79 fps), and the larger of the range of depth-averaged flow velocities (0-0.1 fps) observed in TB4 (See Figure 3) was selected for TB4

Pilot Study Area (= 0.1 fps). These values were plotted on the Hjulstrom curve (Hjulstrom, 1935) to determine the minimum D_{50} of the ecological habitat layer.

3) Tang (1963) and Van Rijn (1984 a, b) - The bed shear stresses for RTA1 (1.44 Pa = 0.03 psf) and TB4 (0.025 Pa = 0.00052 psf) were compared against a table given in Appendix G of Baird (2012) report comprising the values of "Critical Shear Stress for Erosion" for various grain sizes. This table, based on relationships established by Tang (1963) and Van Rijn (1984 a, b) was used to determine the grain size of material (D_{50}).

The largest value of the grain sizes obtained among the three methods for both RTA1 and TB4 Pilot Study Area were then compared against the United Soil Classification System (USCS) matrix (Holtz and Kovacs, 1981) to determine the relevant particle classification for stability.

CALCULATIONS

Recommended Ecological Habitat Layer Thickness

Based on a review of several sand capping projects (See Table 1), the ecological habitat layer thickness or bioturbation allowance generally ranges from 6 to 12 inches. This is similar to the subaqueous cap design guidance from Clarke et al. (2001) which recommends total bioturbation allowance between 20 and 45 cm (8 to 18 inches) for marine environments with sand caps. Thus, an ecological habitat layer with a total thickness of 12 inches consisting of: (i) gravel placed into the voids of the six-inch thick ACB mats; and (ii) six inches of sand used for the isolation and filter layer would account for bioturbation effects and facilitate benthic recolonization.

Grain Size

Grain size calculations were completed using three methodologies: Shields (1936), Hjulstrom (1935), and Tang (1963) & Van Rijn (1984a, b). The calculations used to estimate these grain sizes are provided as follows:

- **Shields (1936)** – The Critical Shields Stress (or Shields Parameter) for sand was selected based on the FHWA (2012) report to be 0.03. The median grain size of the material (D_{50}) was then calculated to be 3.56 mm (~ 0.14 inches) for RTA1 and 0.06 mm (~ 0.0024 inches) for TB4 Pilot Study Area. A hand (manual) calculation for RTA1 is provided as Attachment A.

- **Hjulstrom (1935)** – The depth-averaged flow velocities chosen for RTA1 (1.79 fps) and TB4 (0.1 fps) were converted into metric units, i.e. (54.6 cm/s) and (3.0 cm/s), respectively and then plotted on the Hjulstrom curve to estimate the grain size corresponding to erosion and transport. As seen from Attachment B, the corresponding grain size (D_{50}) is estimated to be ~ 2.0 mm (0.08 inches) for RTA1 and ~ 0.5 mm (0.02 inches) for TB4 Pilot Study Area**.**

- **Tang (1963) and Van Rijn (1984a, b)** – The bed shear stresses chosen for RTA1 (1.44 Pa) and TB4 (0.025 Pa) were compared to the values of "Critical Shear Stress for Erosion" given in Table 2 and the corresponding Grain Diameter Range (D_{50}) was computed as 2 to 4 mm (0.08 to 0.16 inches) for RTA1 and 0.008 to 0.016 mm (0.0003 to 0.0006 inches) for TB4 Pilot Study Area.

The three methodologies estimated similar grain sizes for RTA1 (2 mm to 4 mm) and are categorized SW/SP (Well or poorly graded sands, gravelly sands, with little or no fines) in the Unified Soil Classification System (USCS), as shown in Table 4. In TB4, the minimum stable grain size were estimated to range from 0.008 to 0.5 mm. The largest of the grain sizes (= 0.5 mm) corresponds with SM/SC (Poorly graded, silty/clayey sands with an appreciable amount of fines) in the USCS. However, in lieu of the potential erosion within the voids of and between the ACB mats due to hydrodynamic forces from propeller wash, the voids within and the gaps between the ACB mats will be filled with gravel, which is larger than sand. The use of gravel in RTA1 is similar to what was used for several other capping projects, where grain sizes ranging from coarse sand to gravel were typically selected (Blasland, Bouck and Lee, Inc. 2005; Parsons, 2011; ITRC, 2014). For TB4, where grain size calculations suggest a finer material within the voids of ACB mats would be suitable for stability purposes, it is recommended a larger material (i.e., gravel) be selected to meet the requirements of the ROD. It is anticipated when Baird's hydrodynamic analysis is updated to account for the proposed cap surface, the estimated bed shear stresses and flow velocities in RTA1 and TB4 Pilot Study Area would be reduced due to the increase in flow area. Thus, based on revised modeling, the estimated grain size for hydrodynamic stability during normal operating conditions may be reduced and the selected gravel in RTA1 may be larger than the calculated D_{50}. In RTA1, a gravel or similar material may be used.. In the TB4 Pilot Study Area, gravel will be used to fill the voids of the ACB mats and a sand will be used for isolation and filter layer.

Volume of Material

The total in-place volume of material required: (i) to fill in the voids of ACB mats; and (ii) for placement of the isolation and filter layer in RTA1 and the TB4 Pilot Study Area is provided as Table 5. Volumes associated with construction losses are not provided as volumes are presented as in-place. A hand (manual) calculation is provided as Attachment C.

SUMMARY AND RESULTS

The ecological habitat layer is typically placed on top of the armor layer to fill the voids between stones and helps establish sufficient depth of soft sediment for facilitating benthic recolonization (EPA, 2013). The top of the ecological habitat layer will be placed to be level with the top of the ACB mats and gravel will be placed within the voids of and between ACB mats. It is anticipated, there will be some infrequent erosion of the gravel within the voids of the ACB mats due to vessel traffic, however, this process is similar to movement of sediments in natural estuarine channels and how gravel or sand at the surface of the cap would move if placed within riprap voids. Based on the evaluation presented herein, the ecological habitat layer is expected to remain reasonably stable during normal hydrodynamic conditions (e.g., during flushing tunnel operation).

Based on: (i) the literature review of similar capping projects and a subaqueous cap design for bioturbation depths; and (ii) grain size calculations; an ecological habitat layer consisting of material with an approx. D_{50} of least 2 to 4 mm (4.75 to 75 mm) is recommended. A 12-inch thick ecological habitat layer consisting of: (i) gravel placed into the voids of the ACB mats; and (ii) the sand isolation and filter layer would: (i) account for bioturbation effects; and (ii) facilitate benthic recolonization. The one foot thickness of the ecological habitat layer meets ROD requirements for benthic recolonization, is comparable to several other capping projects reviewed, and is within the recommended bioturbation component cap thickness suggested by Clarke et al. (2001). The ACBs used for the design will be 6 inches thick and open-spaced, thus allowing for the fill of ACB voids with gravel in RTA1 and TB4. Since the ACBs would be underlain by an isolation and filter layer consisting of 6 inches of sand, the total ecological habitat layer thickness of 12 inches will result in adequate depth for facilitating benthic recolonization. The volume of gravel placed into the voids of the ACB mats in RTA1 and TB4 Pilot Study Area for the ecological habitat layer would be approximately 775 in-place cubic yards (ICY) and 169 ICY, respectively. The total volume of material for the isolation and filter layer would be approximately 3,864 ICY and 785 ICY in RTA1 and TB4 Pilot Study Area, respectively.

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TABLES

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Table 1. Summary of Habitat Layer Thicknesses and Grain Sizes for Capping Projects

Project Name	Project Location	Habitat Layer Specifications
Hudson River PCBs Superfund Project (Blasland, Bouck and Lee, Inc. 2005)	New York	A bioturbation allowance of up to 6 inches and median grain size (D_{50}) = 0.02 - 0.08 inches for areas with water velocities less than 1.5 ft/s and (D_{50}) = 0.24 - 0.47 inches for areas with water velocities greater than 1.5 ft/s during a 2-yr flow event.
Focus Puget Sound Capping Pilot Study (HartCrowser Inc. 2012)	Anacortes, Washington	6 inches of habitat layer material.
Onondaga Lake Capping, Dredging, Habitat and Profundal Zone (Parsons, 2011; NYDEC, 2016)	Syracuse, New York	Habitat layer will be minimum 12 inches thick in areas with water depth between 7 and 30 ft.
New York Bight Capping Project (Rhoads and Carey, 1997)	New York/ New Jersey	12 inches of bioturbation allowance.
Black Lagoon – Detroit River (ITRC, 2014)	Trenton, Michigan	6 inches of habitat layer material.

Table 2. Critical Shear Stress for Erosion of Particles of Different Size Classes (Baird, 2012)

Sediment Particle Size Classification	Grain Diameter Range (mm)	Critical Shear Stress for Erosion* Pa
Large Boulders	1024 - 2048	910.7
Medium Boulders	512 - 1024	455.3
Small Boulders	256 - 512	227.7
Large Cobbles	128 - 256	113.8
Small Cobbles	64 - 128	56.9
Very Coarse Gravel	32 - 64	28.5
Coarse Gravel	16 - 32	14.2
Medium Gravel	8 - 16	7.1
Fine Gravel	4 - 8	3.2
Very Fine Gravel	2 - 4	1.3
Very Coarse Sand	1 - 2	0.54
Coarse Sand	0.5 - 1.0	0.25
Medium Sand	0.25 - 0.50	0.17
Find Sand	0.125 - 0.250	0.11
Very Fine Sand	0.0625 - 0.125	0.10
Coarse Silt	0.032 - 0.0625	0.10
Medium Silt	0.016 - 0.032	0.050
Fine Silt	0.008 - 0.016	0.025
Very Fine Silt	0.004 - 0.008	0.013
Clay	0.002 - 0.004	0.010

Bed Shear Stress in RTA1 from Flushing Tunnel and Tidal Impacts = 1.44 Pa

Bed Shear Stress in TB4 from Flushing Tunnel and Tidal Impacts = 0.025 Pa

*Based on the relationships of Tang (1963) and Van Rijn (1984a & b)

Table 3. USCS Definitions of Particle Size, Size Ranges, and Symbols (Holtz and Kovacs, 1981)

Soil Fraction or Component	Symbol	Size Range
Boulders	None	Greater than 300 mm
Cobbles	None	75 mm to 300 mm
(1) Coarse-grained soils:		
Gravel	[illegible]	[illegible] sieve
Coarse		[illegible]
Fine		[illegible] sieve
Sand	S	[illegible] to No. 200 (0.075 mm)
Coarse		No. 4 (4.75 mm) to No. 10 (2.0 mm)
Medium		No. 10 (2.0 mm) to No. 40 (0.425 mm)
Fine		No. 40 (0.425 mm) to No. 200 (0.075 mm)
(2) Fine-grained soils:		
Fines	[illegible]	Less than No. 200 sieve (0.075 mm)
Silt	[illegible]	(No specific grain size—use Atterberg limits)
Clay	[illegible]	(No specific grain size—use Atterberg limits)
(3) Organic Soils	[illegible]	(No specific grain size)
(4) Peat:	Pt	(No specific grain size)
Gradation Symbols Well-graded, W Poorly-graded, P		*Liquid Limit Symbols* High LL, H Low LL, L

Range of calculated grain sizes for RTA1 – 2 to 4 mm (Recommend use of gravel, which is larger, for filling in voids of ACB mats)

Range of calculated grain sizes for TB4 – 0.008 to 0.5 mm (Recommend use of gravel, which is larger, for filling in voids of ACB mats)

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Table 4. Unified Soil Classification System (Holtz and Kovacs, 1981)

UNIFIED SOIL CLASSIFICATION
INCLUDING IDENTIFICATION AND DESCRIPTION

Major division	Subdivision	FIELD IDENTIFICATION PROCEDURES (excluding particles larger than 3 inches and basing fractions on stimated weights)			GROUP SYMBOLS	TYPICAL NAMES
COARSE GRAINED SOILS More than half materials is larger than No. 200 sieve size (The No. 200 sieve size is about the smallest particle visible to the naked eye)	GRAVELS More than half of coarse fraction is larger than No. 4 sieve size (For visual classification, the 1/4" size may be used as equivalent for the No. 4 sieve size) — CLEAN GRAVELS (Little or no fines)	Wide range in grain size and substantial amounts of all intermediate particle sizes			GW	Well graded gravels, gravel-sand mixtures, little or no fines
	GRAVELS — CLEAN GRAVELS (Little or no fines)	Predominantly one size or a range of sizes with same intermediate sizes missing			GP	Poorly graded gravels, gravel-sand mixtures, little or no fines
	GRAVELS — GRAVELS WITH FINES (Appreciables amount of fines)	Non-plastic fines (for identification procedures see ML below)			GM	Silty gravel, poorly graded gravel-sand silt mixtures
	GRAVELS — GRAVELS WITH FINES (Appreciables amount of fines)	Plastic fines (for identification procedures see CL below)			GC	Clayey gravels, poorly graded gravel-sand clay mixtures
	SANDS More than half of coarse fraction is smaller than No. 4 sieve size — CLEAN SANDS (Little or no fines)	Wide range in grain sizes and substantial amount of all intermediate particle sizes			SW	Well graded sands, gravelly sands, little or no fines
	SANDS — CLEAN SANDS (Little or no fines)	Predominantly one size or a range of sizes with some intermediate sizes missing			SP	Poorly graded sand, gravelly sands, little or no fines
	SANDS — SANDS WITH FINES (Appreciable amount of fines)	Non-plastic fines (for identification procedures see CL below)			SM	Silty sand, poorly graded sand-silt mixtures
	SANDS — SANDS WITH FINES (Appreciable amount of fines)	Plastic fines (for identification procedures see CL below)			SC	Clayey sand, poorly graded sand-clay mixtures
FINE GRAINED SOILS More than half materials is smaller than No. 200 sieve size (The No. 200 sieve size es about the smallest particle visible to the naked eye)	IDENTIFICATION PROCEDURES ON FRACTION SMALLER THAN No 40 SIEVE SIZE	DRY STRENGTH (CRUSHING CHARACTERISTICS)	DILATANCY (REACTION TO SHAKING)	TOUGHNESS (CONSISTENCY NEAR PLASTIC LIMIT)		
	SILTS AND CLAYS Liquid limit less than 50	None to slight	Quick to slow	None	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sand with slight plasticity
	SILTS AND CLAYS Liquid limit less than 50	Medium to high	None to very slow	Medium	OL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
	SILTS AND CLAYS Liquid limit less than 50	Slight to medium	Slow	Slight	MN	Organic silts and organic silt-clays of low plasticity
	SILTS AND CLAYS Liquid limit greater than 50	Slight to medium	Slow to none	Slight to medium	OL	Inorganic silt, micaceous or diatomaceus fine sandy or silty soils, elastic silts
	SILTS AND CLAYS Liquid limit greater than 50	High to very high	None	High	CH	Inorganic clays of high organic plasticity
	SILTS AND CLAYS Liquid limit greater than 50	Medium to high	None to very slow	Slight to medium	OH	Organic clays of medium to high plasticity
HIGHLY ORGANIC SOILS		Readily identified by color, odor, spongy feel and frequently by fibrous texture			Pt	Peat and other organic soils

INFORMATION REQUIRED FOR DESCRIBING SOILS

Give typical name; indicate approximate percentage of sand and gravel, max. size; angularity, surface condition, and hardness of the coarse grains; local or geological name and other pe[illegible] an[illegible]

Fo[illegible] on[illegible] ne[illegible] an[illegible]

EX[illegible]

Si[illegible] an[illegible] size; rounded and subangular sand grains coarse to fine; about 15% non-plastic fines with low dry strength; well compacted and moist in place; all[illegible]

Gi[illegible] ch[illegible] ma[illegible] in[illegible] ge[illegible] de[illegible] in[illegible]

Fo[illegible] on[illegible] in undisturbed and remolded strates, moisture and drainage conditions

EXAMPLE:

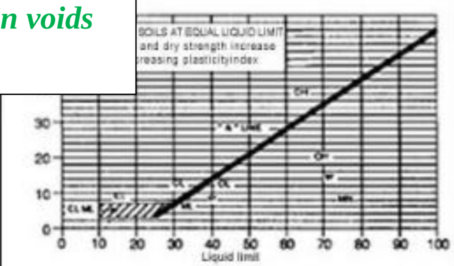
Clayey silt, brown, slightly plastic; small percentage of fine sand; numerous vertical root holes; firm and dry in place; loess, (ML)

LABORATORY CLASSIFICATION CRITERIA

$C_u = \frac{D_{60}}{D_{10}}$ Greater than 4 $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between one and 3	
Not meeting all gradation requirements for GW	
[illegible]terberg limits above "A" line [illegible]th PI greater than 7	Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols
[illegible]terberg limits below "A" line [illegible] PI greater than 7	
$C_u = \frac{D_{60}}{D_{10}}$ Greater than 6 $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between one and 3	
Not meeting all gradation requirements for SW	
Atterberg limits below "A" line or PI less than 4	Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols
Atterberg limits above "A" line [illegible]ith PI greater than 7	

PLASTICITY CHART

[illegible]Y CLASSIFICATION OF FINE GRAINED SOILS



Minimum Particle size classification for RTA1 – SW/SP
(Use of gravel, which is larger, is recommended for filling in voids)

Minimum Particle size classification for TB4 – SW/SP/SM/SC
(Use of gravel is recommended, which is larger, for filling in voids of ACB mats)

Table 5. Summary of Ecological Habitat Layer Material Volumes for RTA1 and TB4 Pilot Study Area

Description		**Required Volume (ICY)**
RTA1	Gravel within the Voids of and Between ACB Mats	775
	Isolation and Filter Layer	3,864
TB4 PILOT STUDY AREA	Gravel within the Voids of and Between ACB Mats	169
	Isolation and Filter Layer	785

Note:

1. Volumes are presented as in-place cubic yards..

FIGURES

CP: **SS**	Date: **5/19/2017**	APC: **GDN**	Date: **5/19/2017**	CC: **MWS**	Date: **5/19/2017**
Client: **RD Group**	Project: **Gowanus Canal Superfund Site**			Project No: **HPH106A**	

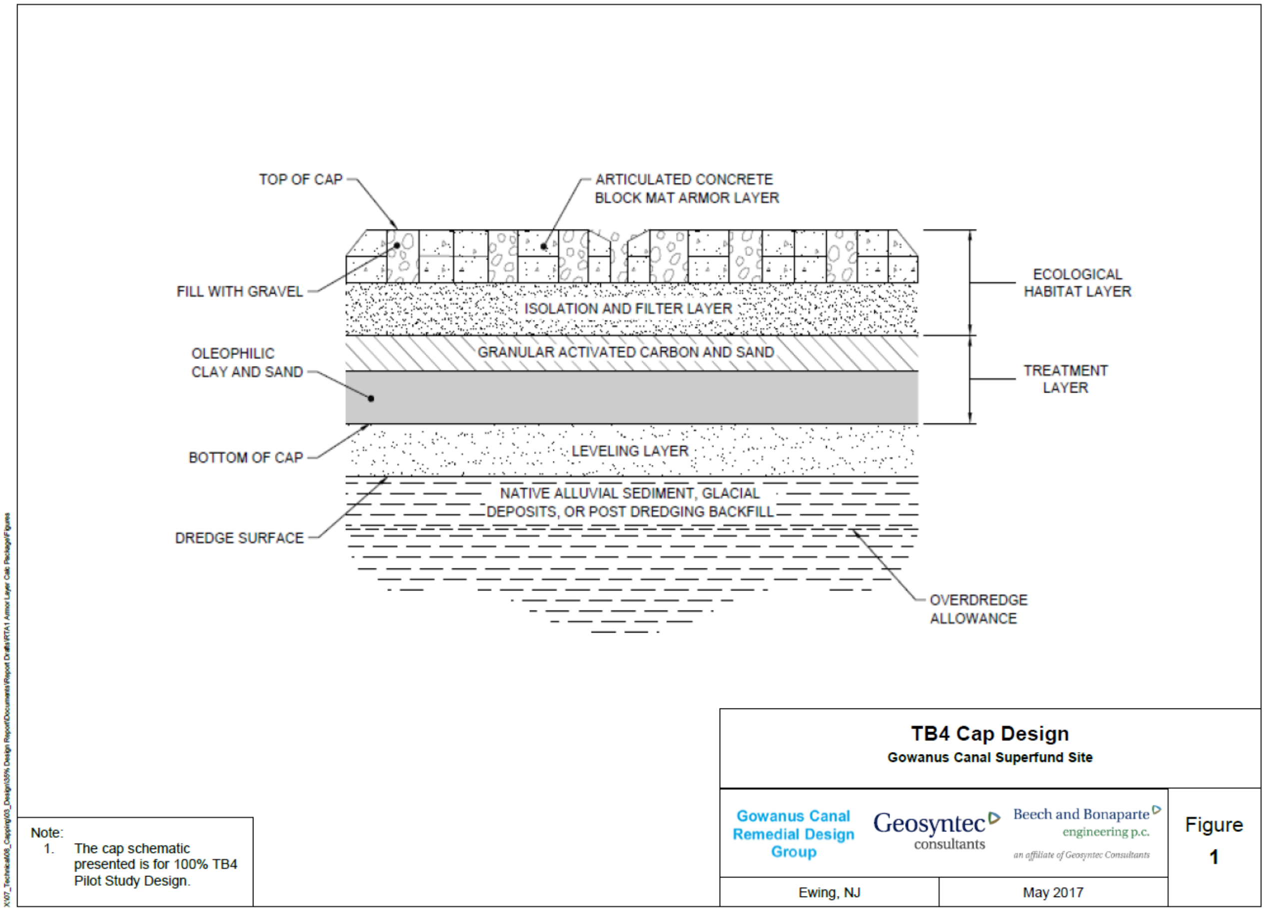


Figure 1. Schematic of the Proposed Cap Design in TB4 Pilot Study Area
(Note: The Cap Design in RTA1 is anticipated to be similar)

CP:	SS	Date:	5/19/2017	APC:	GDN	Date:	5/19/2017	CC:	MWS	Date: 5/19/2017

Client: **RD Group** Project: **Gowanus Canal Superfund Site** Project No: **HPH106A**

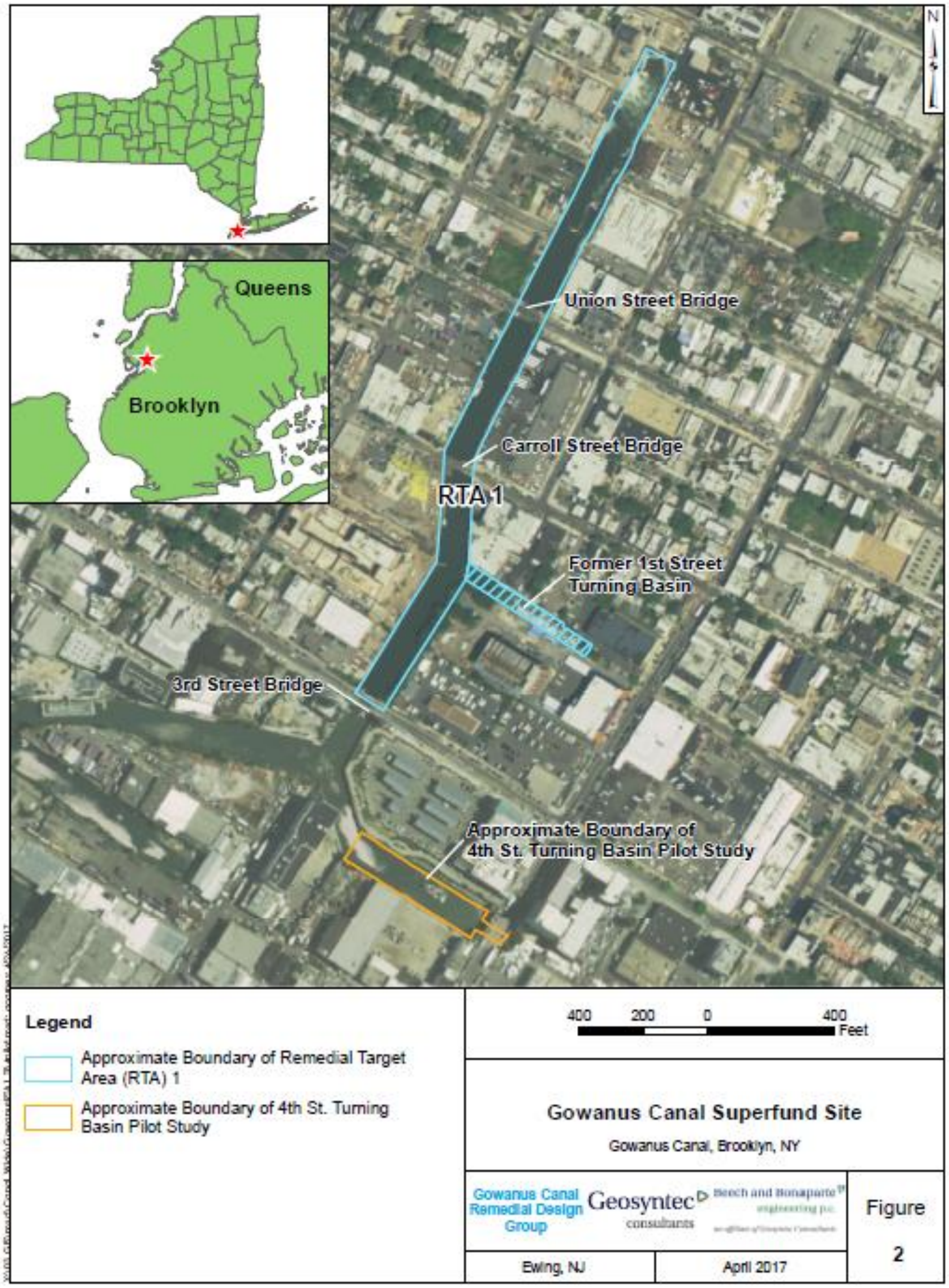


Figure 2. RTA1 and TB4 Pilot Study Area *(Note: The Limits of Capping differ in TB4 from the total area of the TB4 Pilot Study at the western limits and beneath the 3rd Ave. Bridge)*

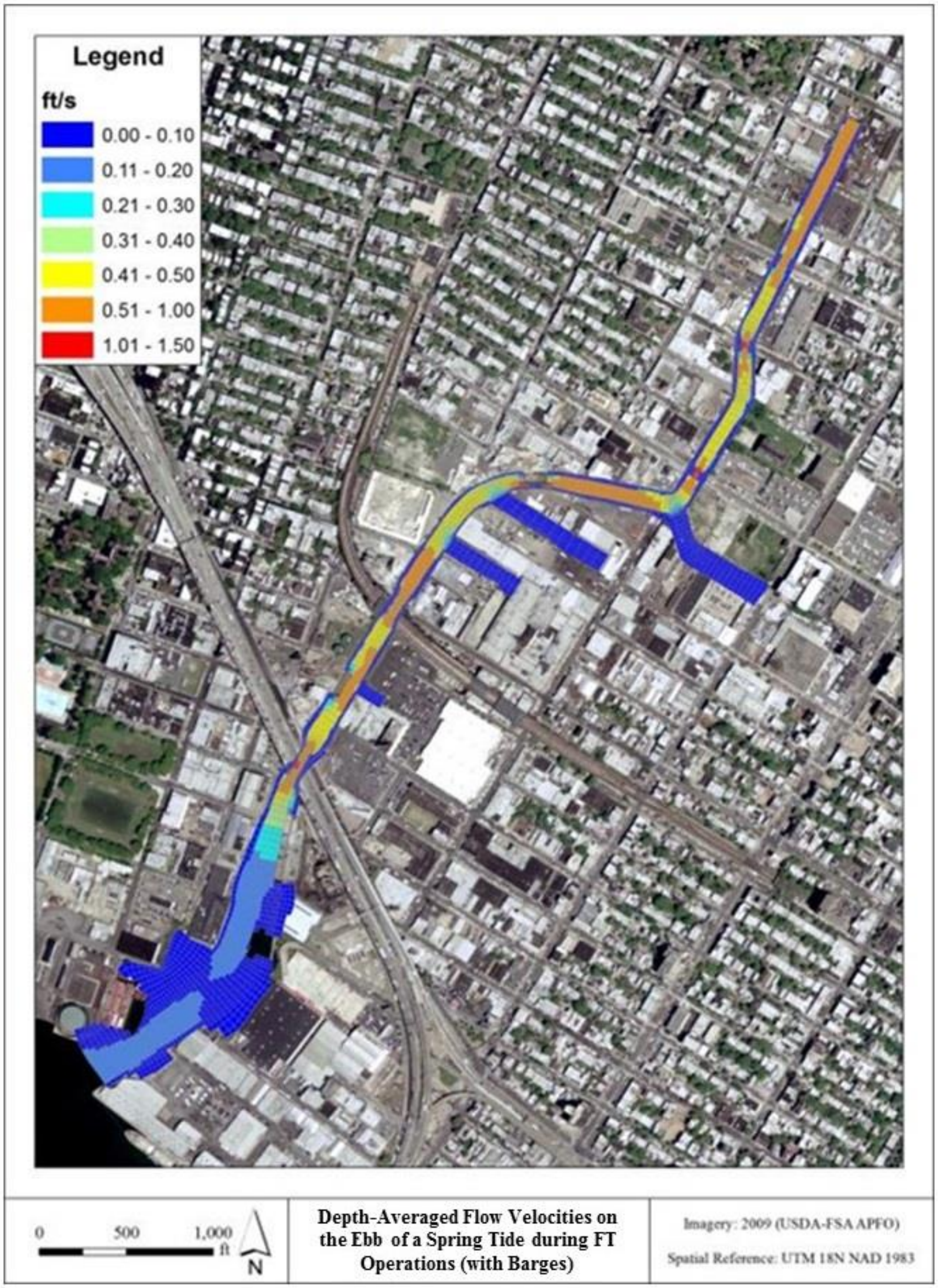


Figure 3. Depth-Averaged Flow Velocities on the Ebb of a Spring Tide during FT Operations (with Barges) (Baird, 2012)

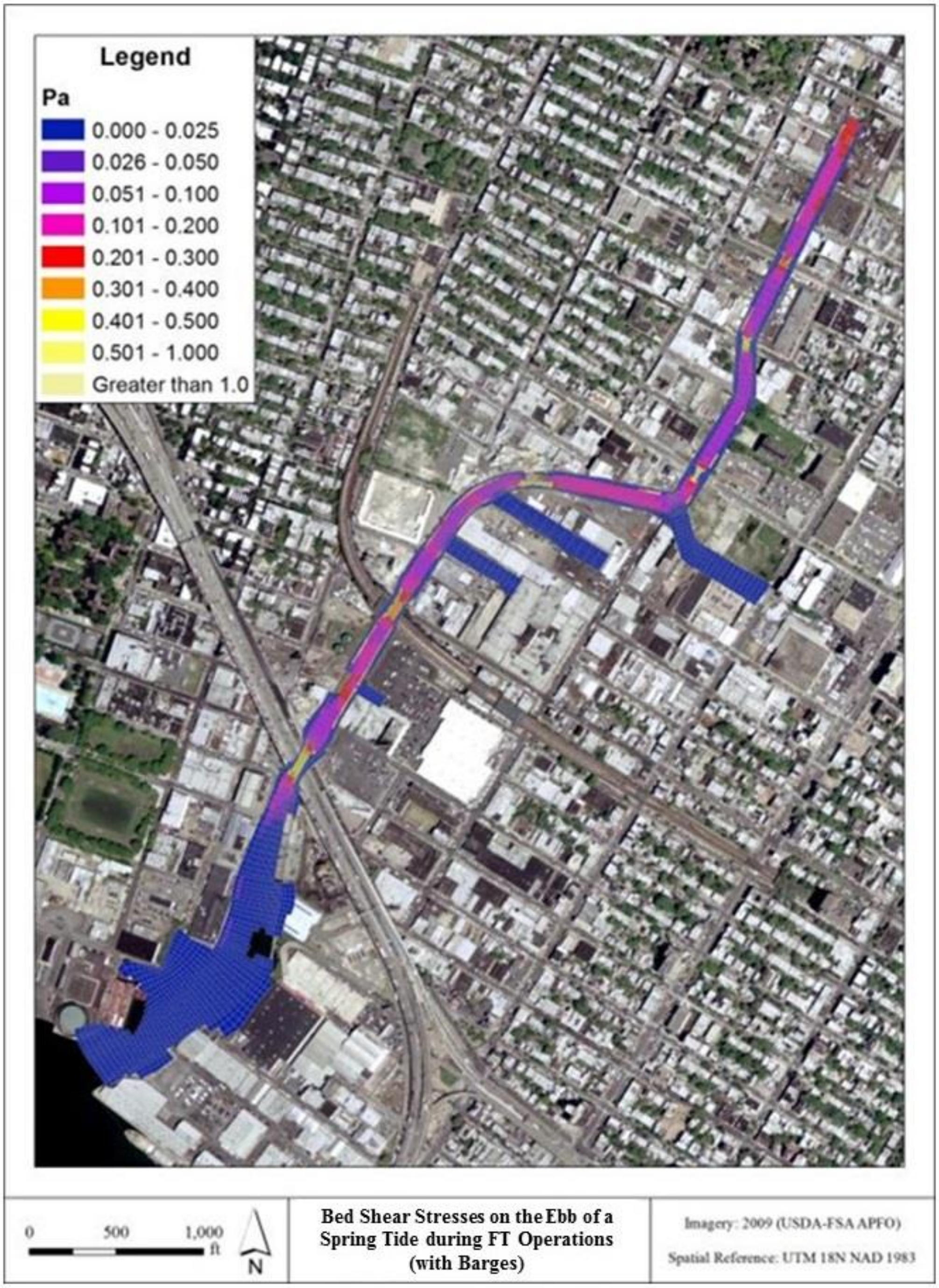


Figure 4. Bed Shear Stresses on the Ebb of a Spring Tide during FT Operations (with Barges) (Baird, 2012)

ATTACHMENT A
HAND CALCULATIONS FOR MEDIAN GRAIN SIZE (D_{50})

CP: **SS** Date: **5/19/2017** APC: **GDN** Date: **5/19/2017** CC: **MWS** Date: **5/19/2017**

Client: **RD Group** Project: **Gowanus Canal Superfund Site** Project No: **HPH106A**

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Written by: SHAURYA SOOD Date: 17/05/17 Reviewed by: MARK SCHMIDT Date: 17/05/17

Client: RD Group Project: Gowanus Canal Project/Proposal No. HPH106A Task No. 53.02

Hand Calculations – Ecological Layer

Median Grain Size (D_{50})

As per the Federal Highway Administration (FHWA, 2012) report, the Critical Shields Stress (or Shields Parameter) for gravel is assumed to be 0.03.

$$\text{Critical Shields Stress } (\theta_c) = \frac{\tau_0}{(\rho_s - \rho) g D_{50}} \longrightarrow (i)$$

where

τ_0 → Peak near bottom shear stress (Pa)
ρ_s → Density of gravel particle (kg/m^3)
ρ → Density of water (kg/m^3)
g → Acc. due to gravity (m/s^2)
D_{50} → Size of grain size/sediment particle (m)

Substituting the values in equation (i)

$$0.03 = \frac{1.44 \text{ Pa}}{(2400-1025)\frac{kg}{m^3} \times 9.81 \frac{m}{s^2} \times D_{50}}$$

$$\therefore D_{50} = \frac{1.44}{9.81 \times 1375 \times 0.03} \text{ m}$$

$$= 0.00356 \text{ m}$$

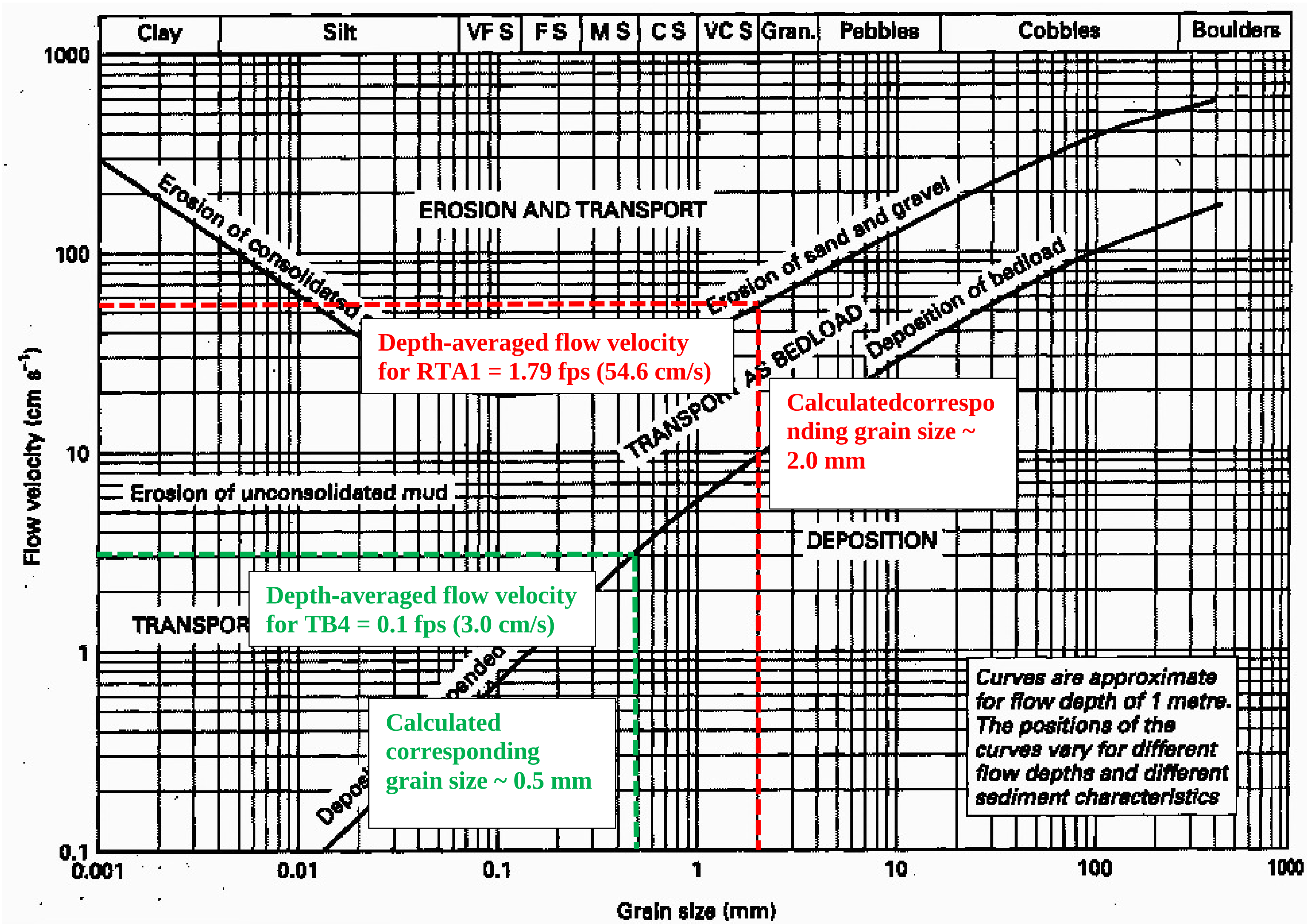
$$= 3.56 \text{ mm} \quad (\simeq 0.14 \text{ inches})$$

$$\therefore D_{50} \simeq 0.14 \text{ inches}$$

ATTACHMENT B
HJULSTROM CURVE

CP:	SS	Date:	5/19/2017	APC:	GDN	Date:	5/19/2017	CC:	MWS	Date:	5/19/2017

Client:	RD Group	Project:	Gowanus Canal Superfund Site	Project No:	HPH106A



ATTACHMENT C
HAND CALCULATIONS FOR VOLUME OF HABITAT LAYER MATERIAL REQUIRED

CP: **SS** Date: **5/19/2017** APC: **GDN** Date: **5/19/2017** CC: **MWS** Date: **5/19/2017**

Client: **RD Group** Project: **Gowanus Canal Superfund Site** Project No: **HPH106A**

Geosyntec consultants

Written by: SHAURYA SOOD Date: 17 / 05 / 17 Reviewed by: Manus Simmons Date: 17 / 05 / 17

Client: RD Group Project: Gowanus Canal Project/Proposal No. HPH106A Task No. 58.02

Hand Calculations – Ecological Layer / Isolation & Filler Layer

Volume of Habitat Material Required

(A) Total Volume of Material required in TB4 Pilot Study Area for Ecological Habitat layer

⇒ (Volume of Gravel within voids of ACB Mats) (I) + (Volume of Gravel within 2" spacing b/w ACB Mats) (II)

(I) Volume of Gravel within voids of ACB Mats = (Selected Thickness of habitat layer) × (Void Ratio of ACB Mats) × (Area of TB4 Pilot Study around Cap Concrete Blocks)

= (0.5 x 20% x 39,957) ft³

= 3995.7 ft³ ≃ 148 in-place cubic yards (ICY)

(II) Volume of Gravel within 2" spacing b/w ACB Mats = [(Area of TB4 Pilot Study around Cap Concrete Blocks) − (Area of ACB Mats)] × habitat layer Thickness

As per the ACB mat plan layout, four ACB mat sizes were used:-

# 1	8' x 20'	=	212 count
# 2	8' x 12'	=	16 count
# 3	8' x 10'	=	37 count
# 4	8' x 4'	=	14 count

⇒ Total Area of ACB mats = 38,864 ft²

∴ Volume of ~~sand~~ Gravel within 2" spacing b/w ACB Mats = (39,957 − 38,864) x 0.5'

= 546.5 ft³ ≃ 21 in-place cubic yards (ICY)

CP: **SS** Date: **5/19/2017** APC: **GDN** Date: **5/19/2017** CC: **MWS** Date: **5/19/2017**

Client: **RD Group** Project: **Gowanus Canal Superfund Site** Project No: **HPH106A**

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Written by: SHAURYA SOOD Date: 18/05/17 (DD MM YY) Reviewed by: MARK Sutherland Date: 19/05/17 (DD MM YY)

Client: RD Group Project: Gowanus Canal Project/Proposal No. HPH106A Task No. 53.02

(B) Total Volume of Material required in TB4 Pilot Study Area for Isolation and Filter Layer

⇒ (In-place volume of sand required for Isolation and Filter layer)

Volume of Sand for Isolation & Filter Layer = (Selected Thickness of Isolation and Filter layer) × (Overall Area of TB4 Pilot Study)

$= (0.5 \times 42{,}324)\ ft^3$

$= 21162\ ft^3 \simeq$ 785 ICY